Comparison of Weighted And Traditional Electrode Configurations In S0 Resonators

Yushuai Liu*†‡ and Tao Wu*†‡¶
Email: liuysh2@shanghaitech.edu.cn; wutao@shanghaitech.edu.cn
*School of Information Science and Technology, ShanghaiTech University, Shanghai, China
†Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, Shanghai, China
‡University of Chinese Academy of Sciences, Beijing, China
¶Shanghai Engineering Research Center of Energy Efficient and Custom AI IC, Shanghai, China

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***Abstract*—The paper reports on electromechanical coupling (k_t^2) enhancement technique for $LiNbO_3$-based laterally vibrating resonators (LVRs). It demonstrates the design and analysis of symmetric (S0) resonators with the weighted structure of 36Y-cut Lithium Niobate ($LiNbO_3$) thin film. This structure can enable the effective exciting of fundamental S0 mode. The resonator orientated 40° to +y in the 36Y-cut plane can achieve high electromechanical coupling coefficient (k_t^2) of 26.2% in S0 mode. Such a high coupling coefficient enables a large bandwidth of acoustic-based RF filters.**

***Index Terms*—lithium niobate ($LiNbO_3$), resonator, high coupling coefficient**

I. INTRODUCTION

The rapidly growing demand for multifunctional wireless communication systems has driven the development of RF front ends [1]. Such RF front ends not only require the adaption to frequency response under the working filters but have high demands for large bandwidth [2]. The demands for resonators of high electromechanical coupling coefficients (k_t^2) has risen rapidly. Many piezoelectric devices have been investigated such as surface acoustic wave (SAW) devices, thin-film bulk acoustic resonators (FBARs) and laterally vibrating resonators (LVRs). In the past decades, different kinds of piezoelectric thin film materials based on these resonators have widely attracted research interests, including aluminum nitride (AlN) [3], [4], lead zirconate titanate (PZT) [5], doped-AlN [6]–[8], [11]–[13] and Lithium Niobate ($LiNbO_3$) [2], [9], [10]. Surface acoustic wave resonators (SAW) based on single crystal piezoelectric material and thin film bulk acoustic wave resonators (FBARs) based on AlN have demonstrated great performances. However, SAWs can not be integrated with CMOS process and FBAR is limited in producing multiple frequency filters on the same chip [6].

Laterally vibrating resonators (LVRs) have shown great advantages for high k_t^2 and multiple frequency on the same chip [1]. In particular, LVRs based on lithium niobate ($LiNbO_3$) have demonstrated extremely high k_t^2 for variety of modes and orientations. The LVRs leveraging transferred $LiNbO_3$ thin films have been developed to feature higher k_t^2 and Q concurrently. $LiNbO_3$ LVRs have exhibited extraordinary high k_t^2 ($> 15\%$) and Q around 1,000 [15]–[17]. Recently, symmetric (S0) LVRs have been reported in suspended thin films of single crystal X-cut [1] and 136° rotated Y-cut [18] $LiNbO_3$.

Compared with other orientations of $LiNbO_3$, 36Y-cut has a big advantage in piezoelectric coefficient e_{11}, which can help excite S0 mode [9]. The weighted S0 mode resonators based on 36Y-cut $LiNbO_3$ thin film have not been well studied. This paper reports on the design of 36Y-cut $LiNbO_3$ fundamental S0 LVRs. We discuss the most effective exciting of S0 mode by adjusting the in-plane rotated angles and normalized $LiNbO_3$ thickness (h_{LN}/λ) for 36Y-cut $LiNbO_3$ thin film. And then, we compare the differences between the weighted electrodes and conventional electrodes configurations and try to explain why the weighted electrodes configuration can excite fundamental S0 mode. A high k_t^2 of S0 resonator can be achieved by optimizing the designed structure.

II. DESIGN AND ANALYSIS

A. *Piezoelctric coefficient related to S0 modes*

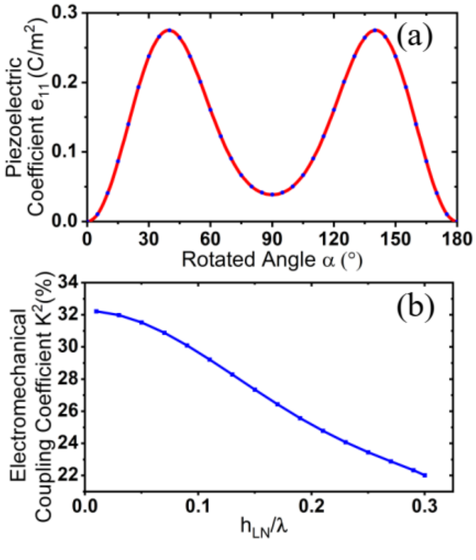

Fig. 1. (a) piezoelectric coefficient e_{11} varies with in-plane propagation direction α for the S0 mode. (b) K^2 of FEA simulation with different normalized thickness of $LiNbO_3$ (h_{LN}) and wavelength (λ) at open and short conditions.

Different piezoelectric coefficients can be be employed to trigger different acoustic modes because lithium niobate ($LiNbO_3$) piezoelectric thin film are anisotropic. The piezoelectric coefficients e_{11} can be used to excite symmetric lamb wave (S0) The relevant piezoelectric coefficient e_{11} can strain in the x-direction. Fig. 1 (a) shows e_{11} versus in-plane propagation direction α for S0 mode. It is obvious that the e_{11} is much larger than the other rotated angles at $\alpha = 40°$ and 140°. Fig. 1 (b) presents the K^2 of S0 with the different normalized $LiNbO_3$ thickness (h_{LN}/λ) within 0.3 (wavelength λ equals twice pitch of IDT). When h_{LN}/λ is lower than 0.1, the S0 mode exhibits larger K^2.

B. Weighted electrodes configuration for exciting S0 mode

The electromechanical coupling (K^2) is calculated using the Berlincourt equation. To maximum K^2, the mutual energy U_m needs to be maximized. It can be expressed as follows [19]:

$$U_m \propto \int (E.d.T)\, dV \tag{1}$$

$$K^2 \;=\; {U_m}^2/(U_e \cdot U_d) \tag{2}$$

where E, d, T and V are the electric field, the piezoelectric coefficient, stress, and volume of the piezoelectric material, respectively. U_e and U_d are the elastic, and electric energy, respectively. Large overlap between E and T can help product large K^2 as shown in Equation (1). Fig. 2 has shown the structure, mode shape and the coupling of E and T. Weighted $LiNbO_3$ S0 resonator structure can excite larger S0 acoustic wave displacement amplitude at the same given electric field compared with the conventional $LiNbO_3$ S0 resonator structure [1]. It can be explained by equ. (1) and (2). For conventional S0 lamb resonator, the U_m will cancel out for fundamental S0 modes when the integral of E and T is zero along the acoustic wave propagation direction as shown in fig. 2 (c). The case of the weighted S0 structure is opposite.The electrodes placed at displacement anti-nodes have the maximum integrate of E and T , which can generate the large exciting efficiency. In conclusion, weighted $LiNbO_3$ S0 resonator structure can excite fundamental S0 acoustic wave mode compared with the conventional $LiNbO_3$ S0 resonator structure.

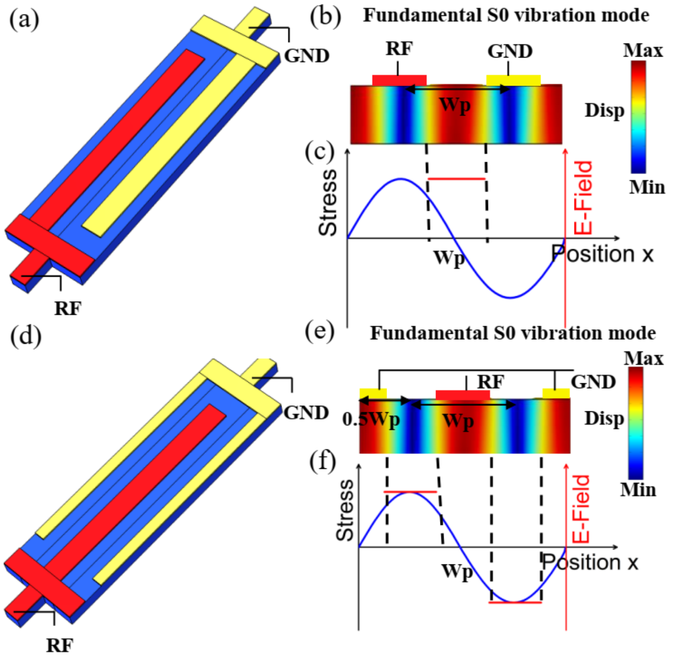

Fig. 2. The COMSOL simulated contour plots show (b),(e) the total displacement of fundamental S0 modes and (c),(f) the coupling of stress and electric (E) field with (a) conventional and (d) weighted electrodes configuration, respectively.

Simulated device responses are compared in Fig. 3 (a) and (b) for both the conventional and weighted S0 resonator electrode configurations, respectively. For $LiNbO_3$ S0 mode resonator, placing the electrodes at the maximum displacement increases the coupling efficiency of S0 mode. The fact of simulated k_t^2 of 0.12% and 26.2% for the conventional and weighted configurations confirm that the weighted electrode configuration can effectively enhance the coupling efficiency for the fundamental S0 mode.

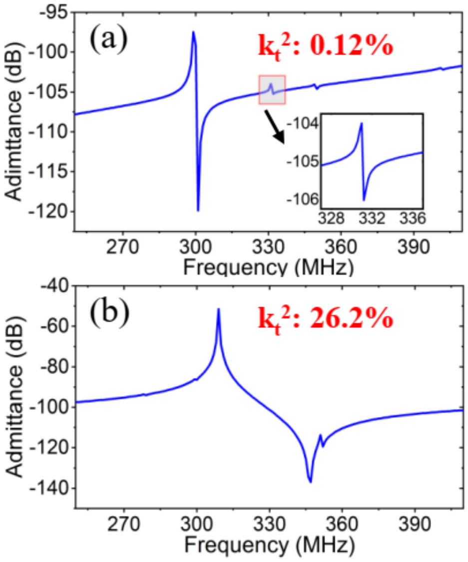

Fig. 3. The simulated admittance of (a) the conventional (partial enlargement represents the admittance of fundamental S0 mode) and (b) the weighted $LiNbO_3$ S0 Lamb wave resonators with fundamental S0 mode at electrodes coverage 0.5.

III. CONCLUSION

A weighted electrode configuration for enhancing the electromechanical coupling of S0 mode based on 36Y-cut $LiNbO_3$ was presented. Compared with traditional electrodes structure, the designed weighted electrodes configuration can enable the maximum exciting efficiency of fundamental S0 resonator.

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